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(71) Applicant: XEROX CORPORATION
Rochester New York 14644 (US)

(72) Inventors:
- Bour, David P.
Cupertino, California 95014 (US)
- Thornton, Robert L.
East Palo Alto, California 94303 (US)

(74) Representative: Goode, Ian Roy
Rank Xerox Ltd
Patent Department
Parkway
Marlow Buckinghamshire SL7 1YL (GB)

(54) Diode laser with tunnel barrier layer

(57) Semiconductor lasers (10) with thin tunnel barrier layers (12) inserted between P cladding layers (26) and P confining/active layers (22). The tunnel barrier layer (12) creates an energy barrier which reduces the leakage of electrons from the active region, if the laser is a double heterostructure laser, or the confining region, if the laser is a quantum well, either single or multiple, laser into the cladding layer.

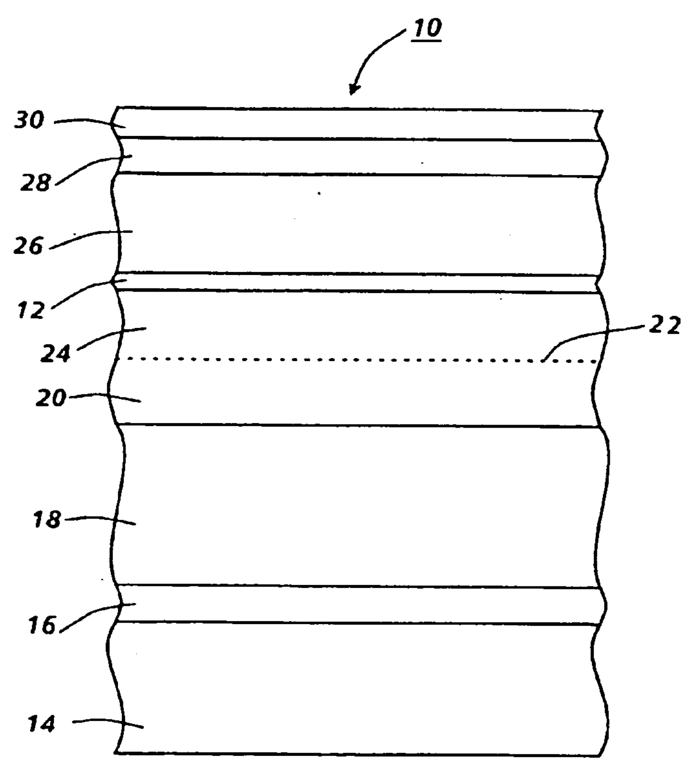

FIG. 1

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to the inventors. Briefly, the tunnel barrier layer 12 between the confining layer 24 and the cladding layer 26 creates a barrier against electron leakage.

Figures 2 and 3 shows conduction band diagrams for AlGaInP lasers, a double heterostructure laser and a quantum well laser, respectively, having AlAs tunnel barrier layers according to the principles of the present invention. For electrons in the l'-valley of the AlGaInP active/confining region, the tunnel barrier layers increase the effective barrier height by more than 0.5 eV. The tunnel barrier layers must be thin, less than 50Å, so that the Γ-valley character of the barrier is retained (as opposed to the lower lying X- or L-valleys).

Experiments on short-period superlattices, resonant-tunnelling diodes, and heterostructure bipolar transistors (with an AlGaAs barrier at the emitter-base junction) have shown that an AlAs tunnel barrier layer presents a very high (Γ-like) barrier when it is sufficiently thin (< 50 Å). On the other hand, as the becomes thicker, the effective barrier height decreases to the X-valley (ie., the lowest energy band edge). Most importantly, for electrons starting in the Γ-valley of the active/confining region, the effective barrier height is the (highest-energy) Γ- bandgap energy of the AlAs layer, provided this layer is sufficiently thin. In essence, for a thin tunnel barrier the finite interband scattering time does not permit relaxation to the X- or L- valleys.

The valence band offset between AlAs and AlInP, although not well known, is estimated to be very small (approximately 50 meV). Consequently, since the AlAs tunnel barrier is p-doped like the AlGaInP cladding layer, there will be negligible valence band discontinuity at the P-clad/barrier layer interface. This is important since the tunnel barrier layer does not inhibit hole injection into the active/confining region, but does act as a highly selective barrier in confining electrons only. The X-bandgap and the L-bandgap energies do not provide electron confinement for Γ-electrons in the active region. Indeed, the energy difference between the X-gap of AlInP and the X- and L-gaps of AlAs (assuming the valence bands line up, either from the low offset and/or p-doping across the barrier) are 180 meV and 50 meV, respectively, both lower in energy compared to the AlInP (as shown in Figures 2 and 3). This emphasizes the requirement that the tunnel barrier layer be made thin so that the probability of interband scattering within the tunnel barrier is low, therefore making the Γ-energy the effective barrier. Moreover, in the quantum well device structure of Figure 3, this structure is only effective when the confining region is direct bandgap, because only Γ-electrons will be confined by the AlAs Γ-energy barrier.

As a result of the small valence-band discontinuity between the AlGaInP P-clad and the AlAs tunnel barrier (whether achieved by p-doping, or an inherently small offset), the increase in the effective electron barrier height is determined by the Γ-bandgap energy difference between the P-clad and tunnel barrier layers. In Figures 2 and 3, the electronic confining potential without th AlAs tunnel barrier lay r is E_o, while th maximum possible potential with the AlAs tunnel barrier is shown by E_1. Again assuming only a small valence band discontinuity, the increase in the electron barrier height is approximately the difference (E_1 - E_o), which is equal to the bandgap difference between AlAs (Γ-gap = 3.02 eV) and Al(Ga)InP (X-gap = 2.35 eV), or 0.67 eV. This represents a tremendous increase from the E_o values of 0.1 - 0.2 eV which are normally encountered in such structures.

Of course, for the tunnel barrier to work as intended, it must be thin. Therefore, some electrons can still tunnel through the tunnel barrier, into the Al(Ga)InP P-clad and contribute to an electron leakage current. Still, such a tunnel barrier does prevent some fraction of the electrons from leaking out, thereby improving the performance of visible lasers. It should be noted that a series of several barriers, in the confining/active region (where the electrons are in the Γ-valley, rather than in the X-valley, like in a high-aluminum-content cladding-layer) could increase the fraction of confined electrons. In that case, the barrier separation should be chosen to avoid resonant tunneling.

The above describes the operation of lasers with AlAs tunnel barrier layers. However, tunnel barrier layers made from other materials are also suitable. For example, an $Al_xGa_{1-x}As$ tunnel barrier layer, preferably with x as close to 1.0 as possible, could also be used. The lower bandgap of $Al_xGa_{1-x}As$, however, compromises barrier height, and so does not make an as effective tunnel barrier layer. Likewise, since the tunnel barrier layer is thin, it need not be constructed of a lattice-matched material. For instance, GaP or AlGaP, which have high direct bandgap energy (compared to the Γ-bandgap energy of AlAs, GaP's Γ-bandgap is lower, while AlP's is higher) could also be used to create tunnel barrier layers. Similarly, the higher bandgap II-VI (ZnMgSSe) or nitride III-V (AlGaInN) alloys could also be used. However, these materials are generally more difficult to prepare than AlAs, and in practice their incorporation into an AlGaInP red laser is not straightforward. Other possible materials include AlGaAs, ZnSSe, and GaN.

While the use of tunnel barrier layers in AlGaInP lasers is described above, primarily because electron leakage is a particularly important problem in such lasers, other types of laser diodes can benefit from the principles of the present invention. For example, an AlAs tunnel barrier layer could also be used to suppress leakage in AlGaAs laser diodes, especially at short (700 nm band) wavelengths where leakage current begins to appear. Similarly, a GaP tunnel barrier layer could reduce leakage in aluminum-free (GaInAsP/GaInP) 808 nm lasers, wh r leakage is an issue becaus of the relatively small confining potential; or in 980 nm (GaInAs/GaAs/GaInP) lasers (although leakage is not generally a problem in these structures, they are sometimes operated at elevated temperatures). Electron leakage

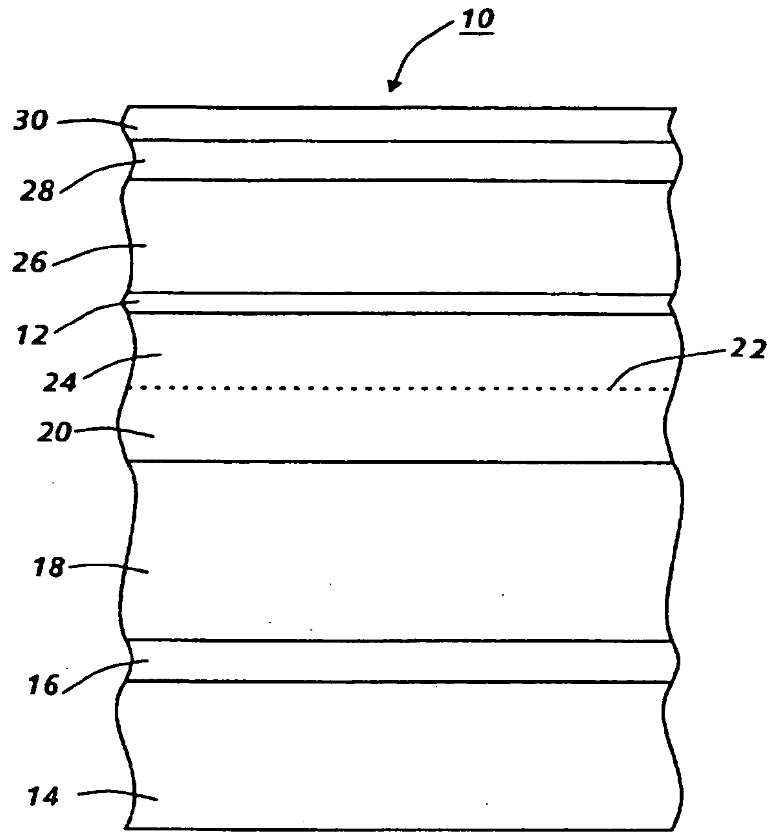
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FIG. 1

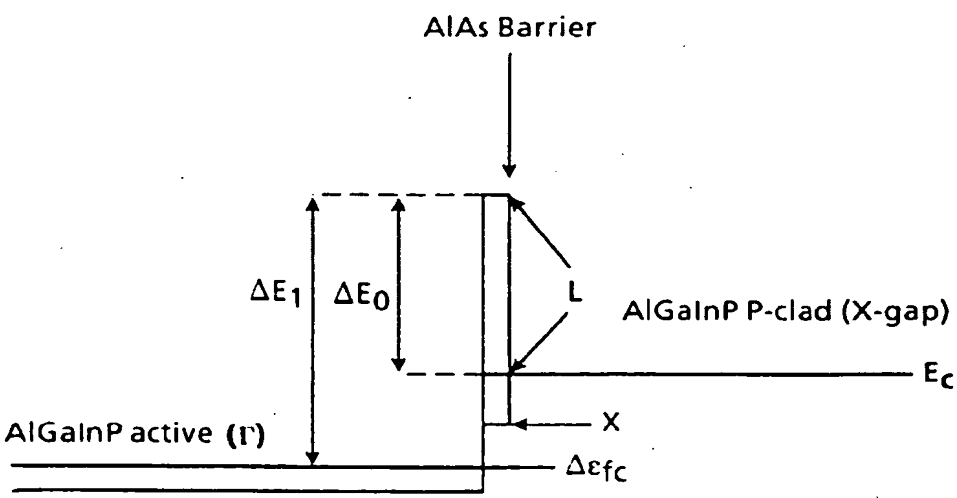
AlAs Barrier
ΔE1
ΔE0
L
AlGaInP P-clad (X-gap)
Ec
X
AlGaInP active (Γ)
Δεfc

FIG. 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 8534

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	GB-A-2 196 789 (SHARP KK) 5 May 1988 * the whole document *	1-3,10	H01S3/19
A	EP-A-0 506 049 (FUJITSU LTD) 30 September 1992 * column 6, line 11 - column 9, line 12; figures 2,3 *	1-3	
A	EP-A-0 213 705 (SHARP KK) 11 March 1987 * page 3, line 5 - page 4, line 12 * * page 6; figures 1,3 *	1-3,10	
A	EP-A-0 540 799 (IBM) 12 May 1993 * page 8, line 41 - page 9, line 40; figures 6,9; table 2 *	1	
A	PATENT ABSTRACTS OF JAPAN vol. 011 no. 004 (E-468) ,7 January 1987 & JP-A-61 181185 (NEC CORP) 13 August 1986, * abstract *	1,4	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	US-A-4 862 471 (PANKOVE JACQUES I) 29 August 1989 * column 1, line 60 - column 2, line 34; figure 1 *	1,8	H01S
A	EP-A-0 619 602 (SONY CORP) 12 October 1994 * column 5, line 34 - line 47; figure 1 *	1,6,7	
A	EP-A-0 518 320 (SUMITOMO ELECTRIC) 16 December 1992 * column 2, line 27 - column 3, line 29 * * column 6, line 30 - column 7, line 14; figure 4 *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 March 1996	Stang, I

CATEGORY OF CITED DOCUMENTS

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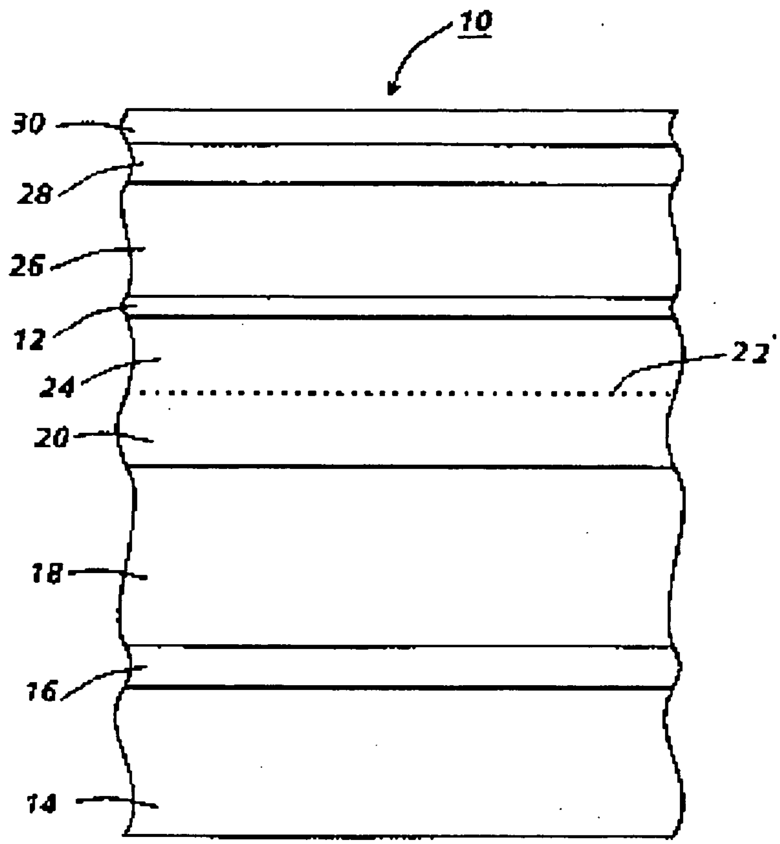
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FIG. 1

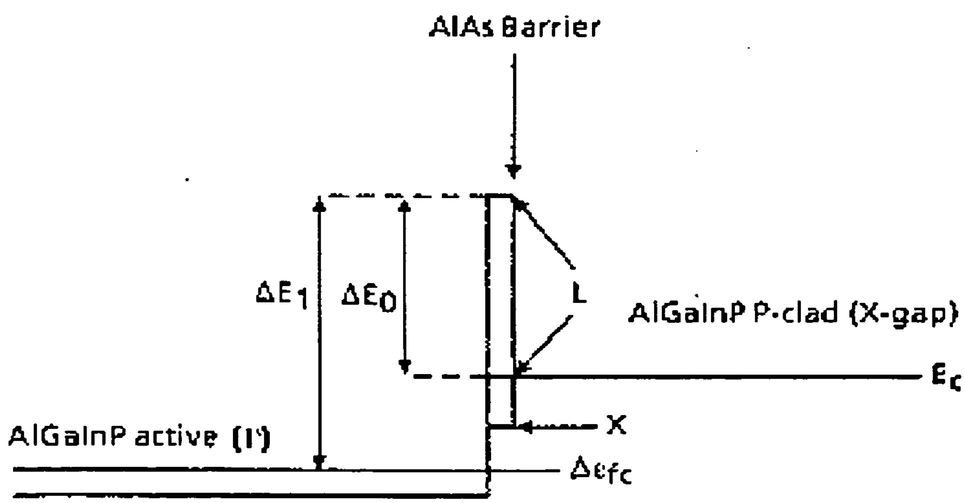
AlAs Barrier
ΔE_1
ΔE_0
L
AlGaInP P-clad (X-gap)
E_c
X
AlGaInP active (Γ)
Δe_{fc}

FIG. 2